Missions in Low *T* Environments: Architectures, Issues, Failures

By

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Overview

- Definition
  - Mars
  - Titan
  - Other Cold Places

- Missions operating in low *T* environments
  - Past, current, future

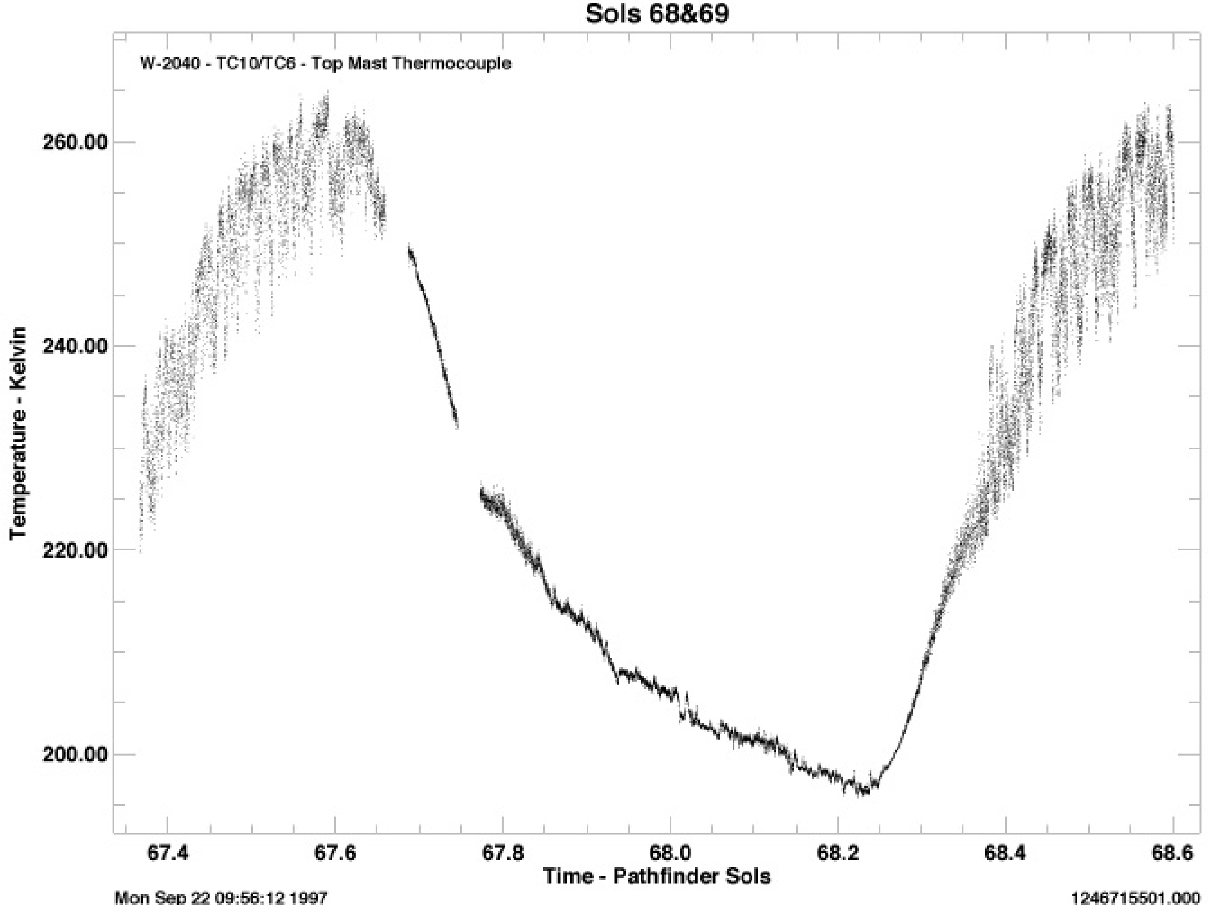
- Effects of Low *T* on Probe Architecture & Subsystems
  - Power, Electronics, Structural, Thermal, Mobility

Definition: What (and Where) do we mean by "Low Temperature"?

- 'Low *T*' is regarded as below -55°C (electronics limit)
- May be coupled with deep thermal cycling, e.g. Mars
- 'Greenhouse effect' relative to airless worlds
- Atmosphere acts as a heat conduction path – e.g. forced convection during parachute descent
- Heat loss issues may in fact be greater for a mission to an atmosphere than to a less cold, airless body
- The *T* of a probe element is in general not the same as the natural *T* of its environment (thermal design, heat capacity,…)
- May also need to avoid overheating, e.g. during cruise or early afternoon
- Moving from low to high *T* in humid atmosphere may produce condensation on probe

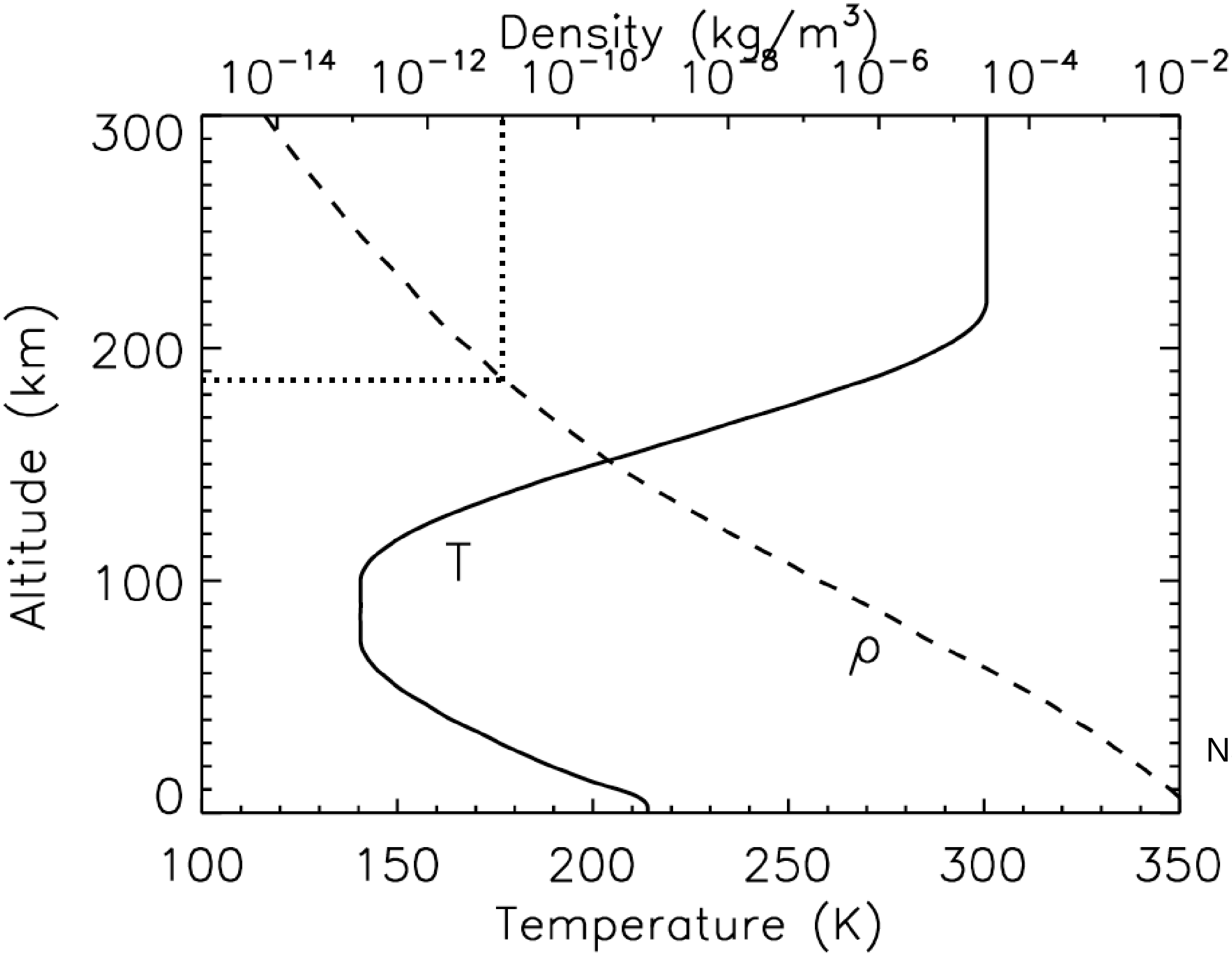
Martian Atmospheric Temperature (1m above surface)

- Mars: -143°C to +27°C (surface); see ref models
  - Large diurnal variation (e.g. Phoenix, Sol 13: -80°C to -32°C)



  - Variations with latitude, topography, surface properties,…

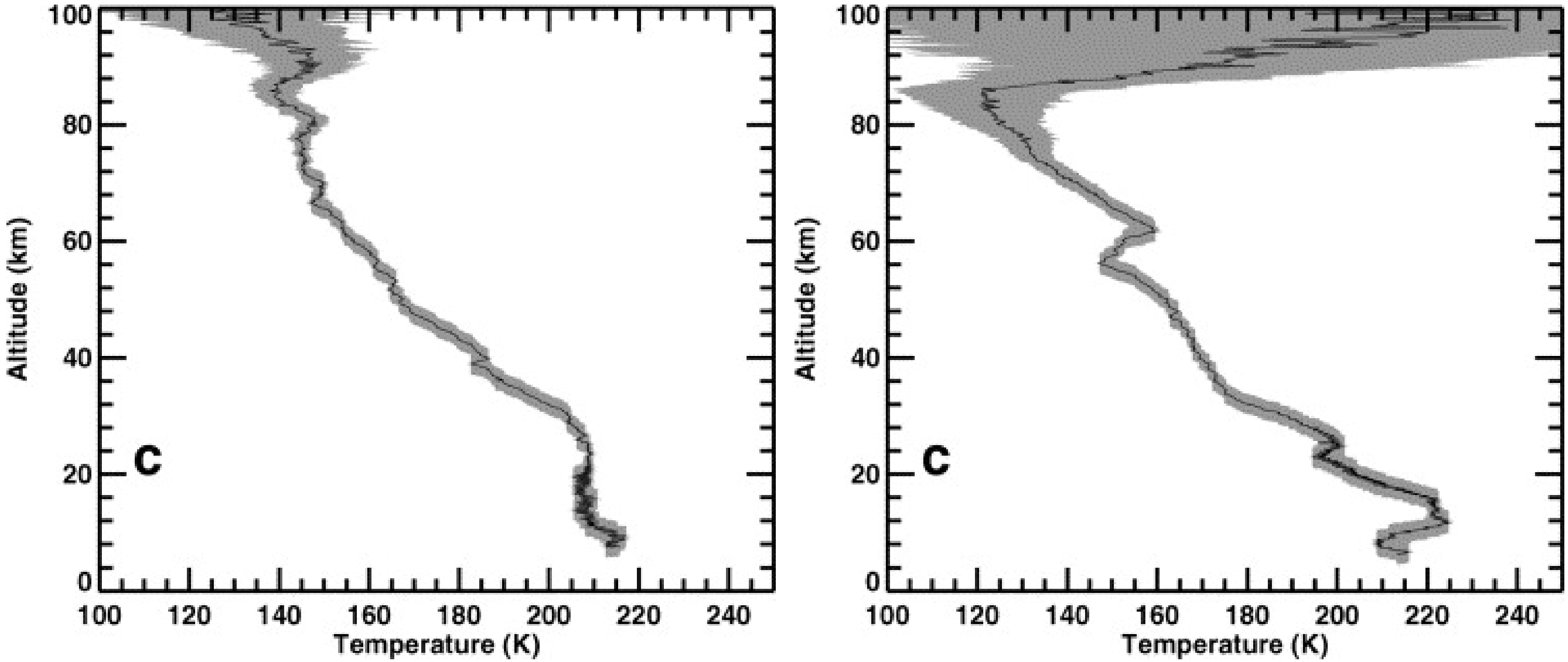
Mars Atmospheric Profile



Nair *et al.* (1994)

- See also Mars Climate Database, Mars-GRAM, TES & THEMIS data,...

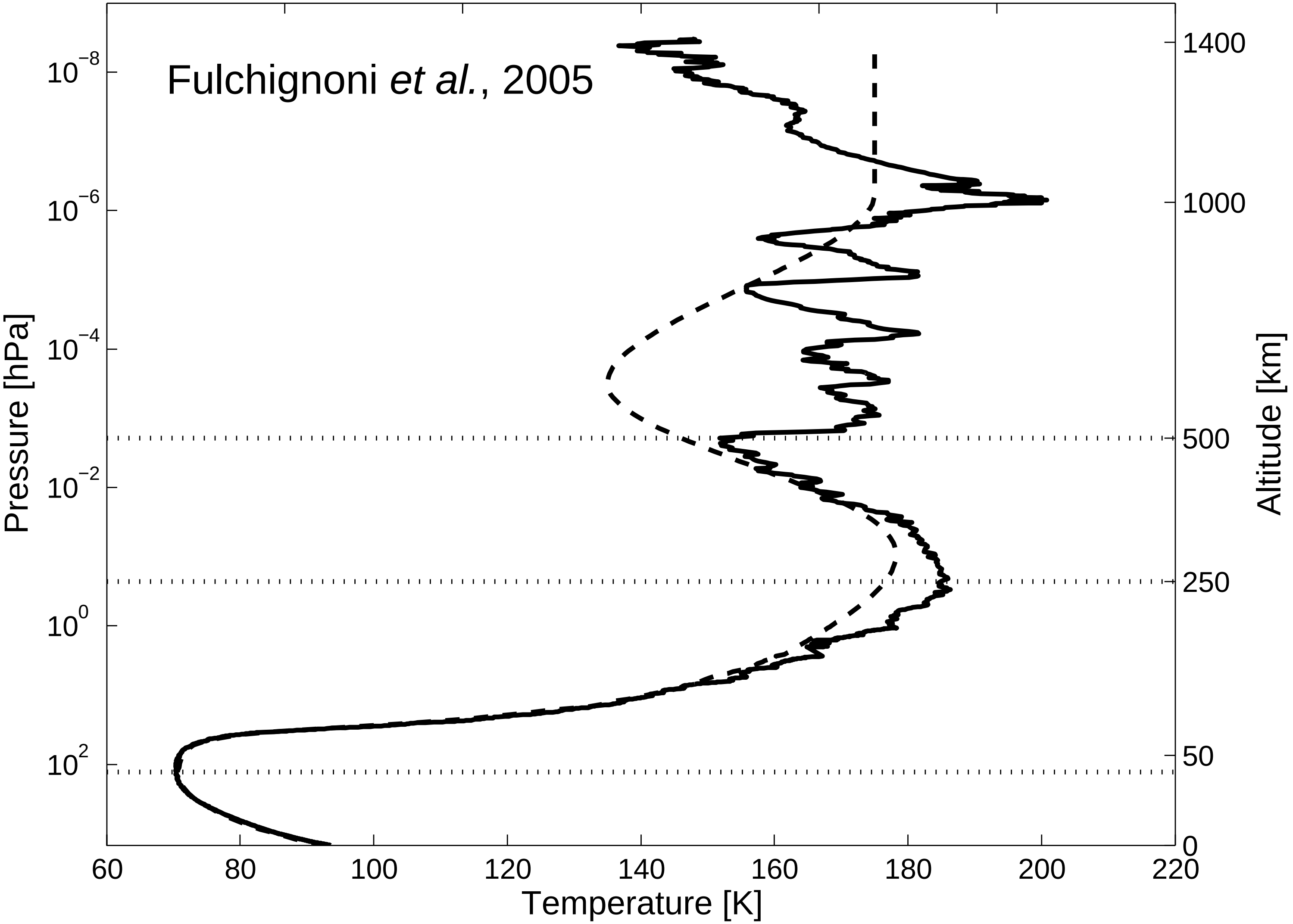
Mars Atmospheric Profiles from Spirit & Opportunity



Withers and Smith, 2006

Temperature Ranges for Worlds with Atmospheres

- Titan: -178°C (surface), ~-203°C (tropopause ~40km)
  - Small diurnal variation

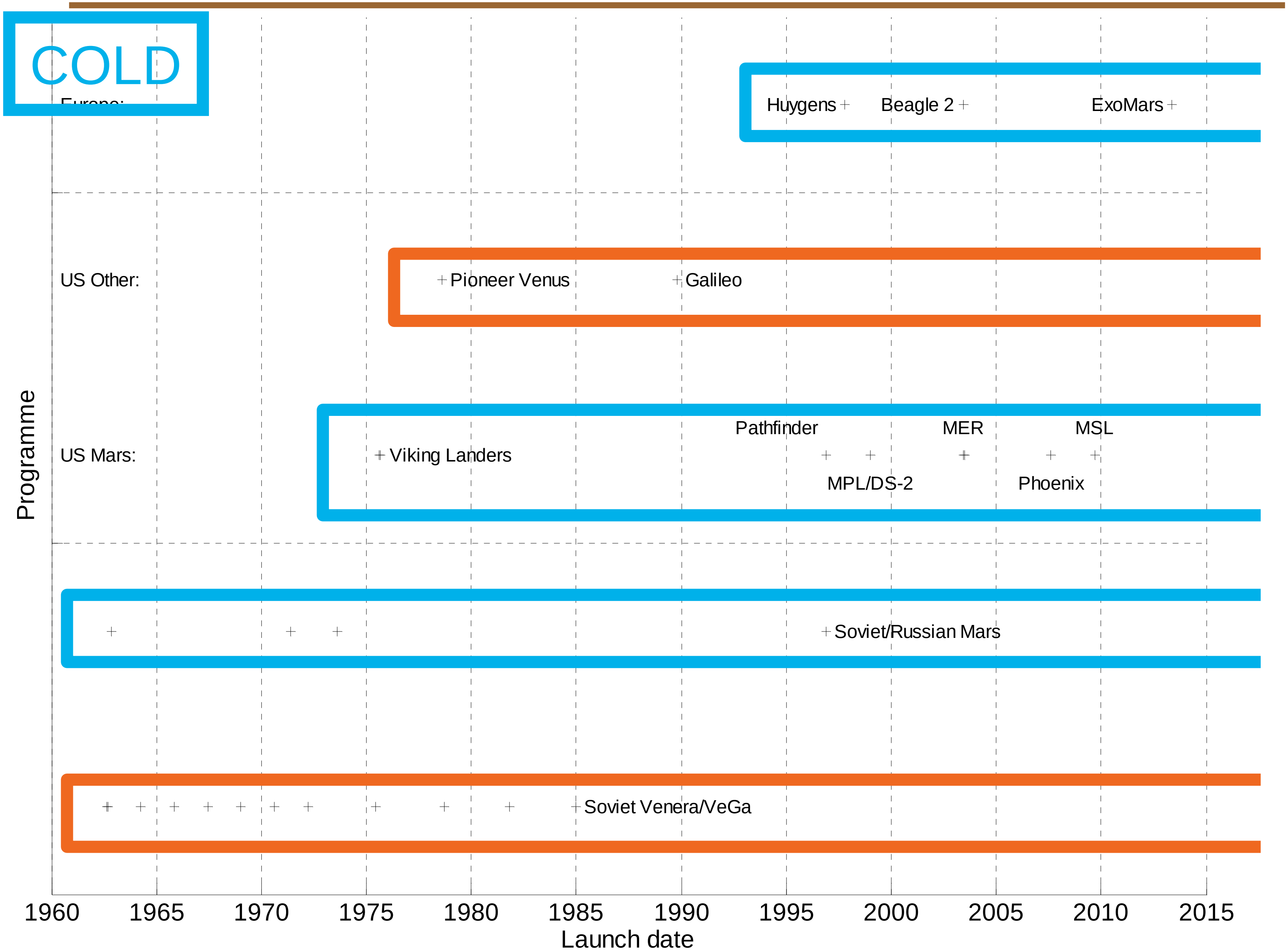


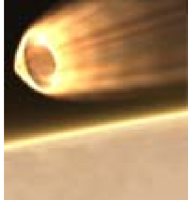
Some Other Cold Places

- Low *T* challenges also (in fact predominantly) faced by orbiter / flyby spacecraft, airless body landers and cooled optics / focal plane instruments
- Deep Space / Outer Solar System (Pioneer 10/11, Voyager 1,2, New Horizons, Galileo, Cassini, Rosetta, Juno,…)
- Cometary nuclei (Philae) (~-150°C)
- Lunar night (-160°C) & shadowed craters (-230°C)
- Cooled s/c assemblies (e.g. IR telescope optics & focal plane)
- Icy satellites
  - Enceladus: -193°C (equator), -188°C (S pole)
  - Europa: -180°C (surface)
  - Triton: -235°C (surface)

In Situ Missions to Worlds with Atmospheres

HOT



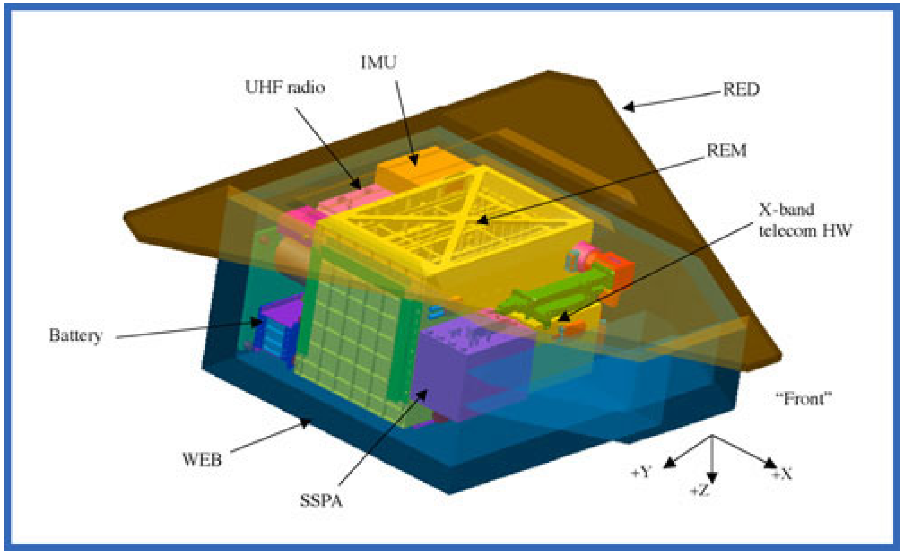


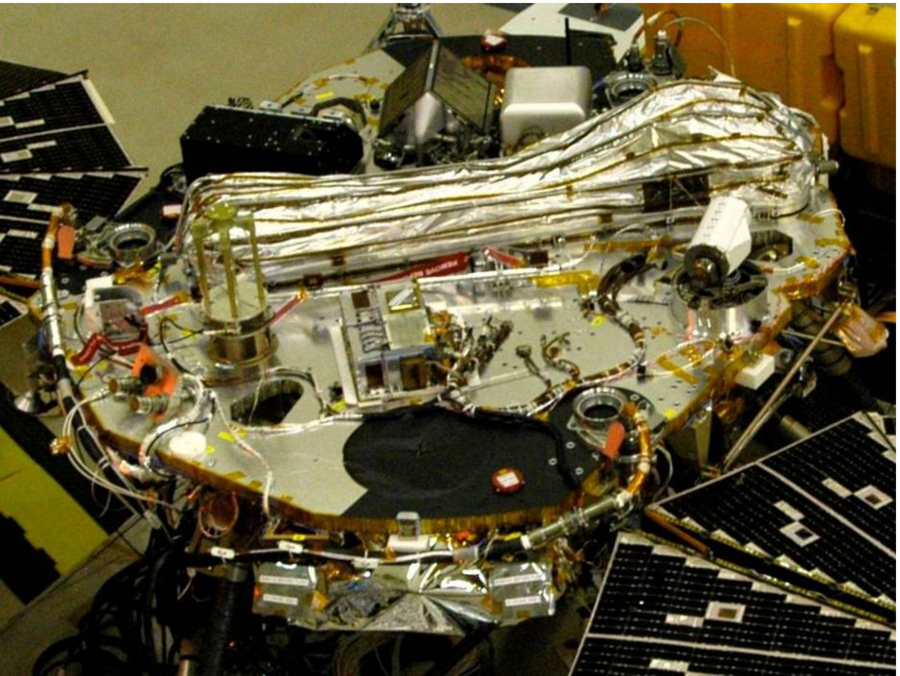
Mars In Situ Missions

- 2MV-3 probe
- M-71 landers (Mars 2,3)
- M-73 landers (Mars 6,7)
- Viking Landers*
- Mars 96 Penetrators*
- Mars 96 Small Stations*†
- Mars Pathfinder
- Sojourner†
- Mars Polar Lander
- DS-2 Mars Microprobes
- Beagle 2
- MER (Spirit & Opportunity)
- Phoenix
- MSL*
- ExoMars†

- *RTG power & thermal
- †RHUs

MER, MPL, Phoenix



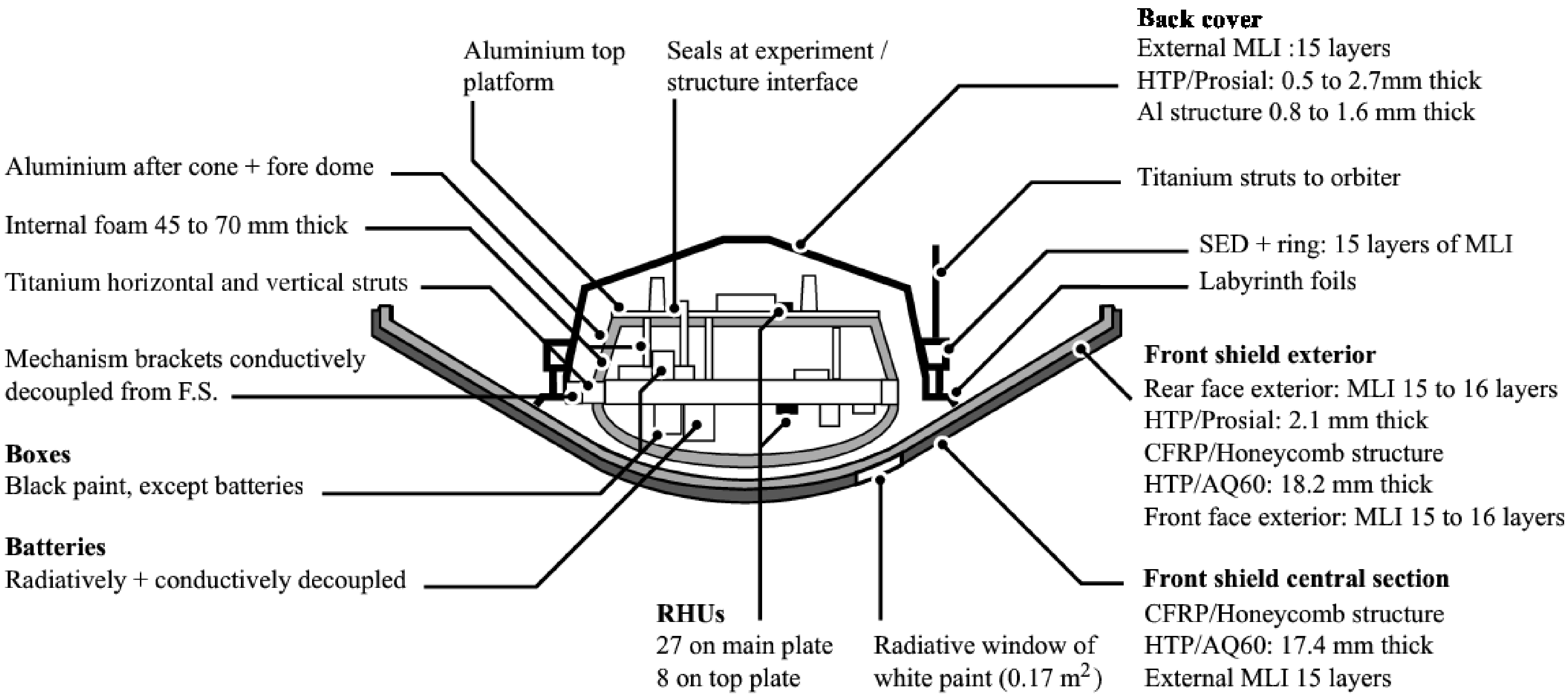


- Warm Electronics Box (WEB) underneath an equipment deck

Huygens

- Forced convection during descent
- Foam insulation (Basotect)
- RHUs
- Minimal sensors exposed
  - HASI TEM, PWA
  - SSP ACC-E, API-V, API-S, PER, THP, REF, DEN
  - DISR apertures
  - GCMS & ACP inlets
- Probe also had to cope with warm Venus flyby
- Higher than predicted heat losses around parts of the probe connected to the outside – thermal model underpredicted losses?

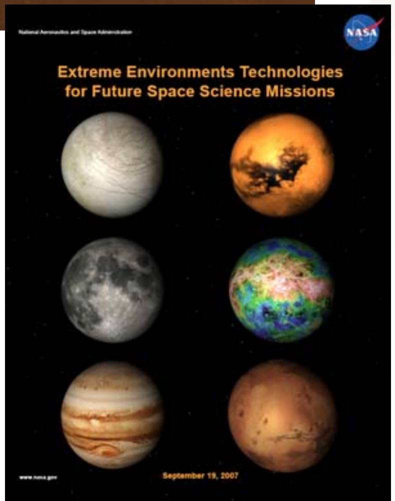
Huygens Thermal Design



J. Garry (after ESA)

Future Missions to Low *T* Environments

- Mars
  - Sample Return
  - Balloon
  - Polar caps
  - Caves
- Titan
  - Balloon
  - Lander
  - Ocean explorer
- Saturn, Uranus, Neptune entry probes



Kolowa *et al.*, Extreme Environment Technologies for Future Space Science Missions. JPL D–32832, NASA, 2007. http://solarsystem.nasa.gov/multimedia/downloads/EE-Report_FINAL.pdf

Effects of Low T on Probe Architecture & Subsystems

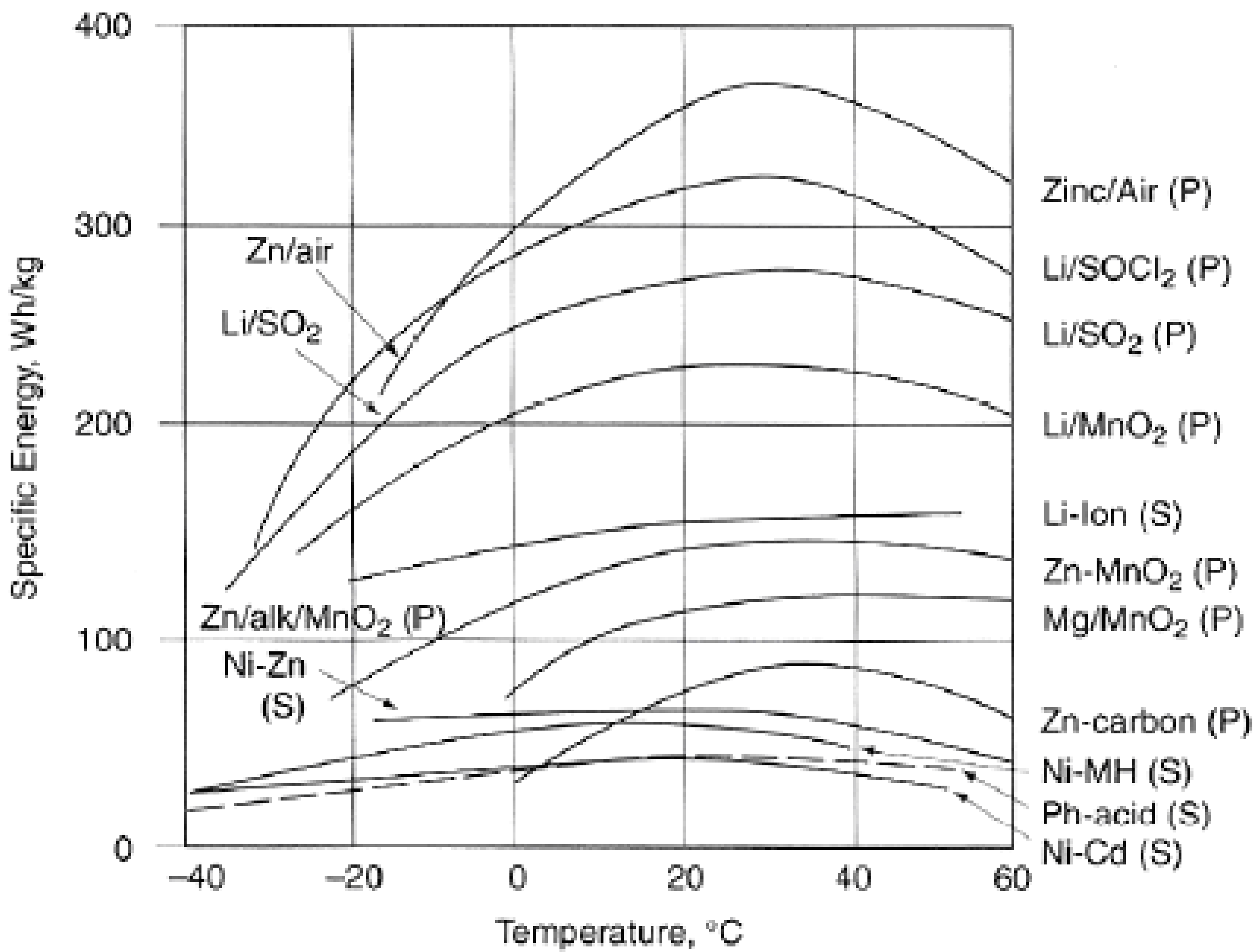
- Low *T* has consequences for many subsystems:
  - Power (Batteries, RTGs, Solar Arrays, Fuel cells, Flywheels, Capacitors)
  - Electronics
  - Communications
  - Structure
  - Thermal
  - Mobility
  - Propulsion
  - …

- Probes convert stored or absorbed energy to heat, RF emission and mechanical work

Effects of Low *T* on Power

- Increased efficiency at low *T*, so fall off vs. *r* from Sun goes not as r^{-2} but $r^{-1.7}$.
- Lower solar intensity reduces temperature, but forces larger area arrays
  - Practical limit being pushed by LILT (Low Intensity, Low *T*) array technology
  - Beyond that limit, nuclear is only option (RTG, MMRTG, Stirling Cycle RTG)
- Heat from RTGs is a useful by-product in a low *T* environment, for keeping electronics (and balloon gas) warm
- Batteries stop working at low *T*; current limit is around -40°C (Li-ion) BUT new technologies under development
- See sections 4.3.5 and 5.2.4 of JPL report
- Performance metrics

Figure 4.31: The effects of temperature on the performance of various primary and rechargeable commercial batteries.



6th International Planetary Probe Workshop, Atlanta, Georgia 06/21-22 2008
Short Course on Extreme Environments Technologies

Effects of Low *T* on Electronics

- Sections 4.3.2 and 5.2.2 of JPL report
- Limited commercial demand for components
- Thermal cycling – wear on solder joints
- Performance metrics

Effect of Low *T* on Structure

- Low *T* makes many materials brittle
- Differential thermal expansion – degradation of joints
- Implications for
  - Structural components
  - Parachute systems
  - Balloon envelopes
  - Icy satellite penetrators

Effects of Low *T* on Thermal Design

- Heat loss shortens a mission and/or increases the resources needed to maintain temperature
  - Solar absorbers (e.g. Philae, Beagle 2)
  - Insulation (e.g. Basotect foam in Huygens, aerogel in Sojourner)
  - RHUs (^{238}Pu, ^{210}Po)
  - Electrical power
  - Phase-change materials

Effects of Low *T* on Mobility

- Mechanisms – operation of gears and bearings below -130°C limited to 1,000,000 cycles, and drive and position sensors limited to -130°C
- Cold electronics can greatly simplify cabling to wheels, etc.
- Sections 4.4.2, 4.4.4, 5.3.2, 5.3.4 of JPL Report
- Performance metrics

Conclusions

- Coping with low *T* is less challenging than coping with high *T*
  - Heating easier than cooling
- Importance of good models
- Trade-off between Low *T* technologies (High cost? Lower TRL? Worse performance?) and providing (where feasible) a warm environment (e.g. ebox)
- Current and foreseen architectures still centred around warm compartment for battery & electronics, with insulation and heating
- Many sensors and subsystems need to be outside, however
- What new measurements or probe architectures might be enabled by low *T* technologies?
- What testing strategy for low *T* atmospheric environment?